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ORIGINAL ARTICLE

Wastewater re-use for peri-urban agriculture: a viable option for adaptive water management?

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Abstract Urbanization is known to spur land modification in the form of conversion of common land to human settlements. This factor, combined with climate variability, can alter the duration, frequency and intensity of storm drain overflows in urban areas and lead to public health risks. In peri-urban regions where these risks are especially high it has been argued that, when domestic wastewater is managed, better prospects for freshwater water savings through swaps between urban water supply and irrigated agriculture may be possible. As a consequence of re-use of domestic wastewater, expenditure on inorganic inputs by farmers may decline and source sustainability of water supply could be enhanced. Given the fact that, at present, approximately 20 million ha of land worldwide is being cultivated by re-using domestic wastewater, this paper draws on evidence from India to explore: (1) the economic costs–benefits of wastewater reuse in the context of hypothesized links to climate variability; (2) the role of local farming practices, market conditions and crop variety in influencing wastewater reuse in agriculture; and (3) the role of inter-governmental financing in influencing the selection of technical adaptation options for collection, treatment and disposal of wastewater.

Keywords Peri-urban · Water and sanitation · Services · Public health · Climate variability · Adaptation · Asia

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Introduction

One of the consequences of urbanization is land modification; for example, common land is occupied and leveled to accommodate new construction. This factor, combined with gradient dynamics, can alter the intensity and direction of water flows in urban areas. In developing countries, wastewater usually enters storm drains and rainfall variability can result in increased intensity, frequency and duration of storm drain overflows. Inadequate source separation of domestic wastewater from rainwater and solid waste followed by necessary treatment can result in transport of contaminants into surface and groundwater sources that are important sources of drinking water.[1] Over time, with deposition of solid waste, storm drains can silt

[1] The primary role of sewerage is to transport pollution from one point to another and ultimately to the wastewater treatment plant. Interactions between sewerage and sewage works depend very much on the type of the sewer system (separate or combined). In some countries, especially in newly developed and modern cities, one finds up to three separate systems in place: sanitary sewers, industrial sewers and stormwater drainage (Brdjanovic et al. 2004).

up with consequences for public health on account of mosquito breeding due to stagnant water, inundation of low lying slum localities, and destruction of crops under peri-urban agriculture. However, on the flip side, when wastewater is better managed, significant economic benefits can be derived in developing countries through reuse for productive purposes like agriculture, kitchen gardens and poultry rearing[2] (Jimenez and Asano 2008).

Some of the direct benefits of wastewater collection and reuse could include double cropping and lower input costs for agriculture (Rijsberman 2004). There may also be important economy-wide benefits of encouraging freshwater swaps through use of treated domestic wastewater for agriculture.[3] For instance, source sustainability of the urban water supply could be enhanced, agricultural productivity may increase and farm incomes can rise. These hypothesized benefits notwithstanding, an integrated analysis of economic costs–benefits of wastewater reuse in the context of purported links to climate variability is currently unavailable (Scott et al. 2000; Van der Hoek et al. 2002; Ensink et al. 2002; IWMI 2007). Another issue that has been unexplored by the literature on reuse relates to the role of inter-governmental financing in influencing selection of technical options for collection, treatment and disposal of wastewater. Policy experience suggests that the preference in developing countries is for infrastructure projects that promote end of pipe solutions that involve investments in underground drainage and expensive treatment facilities that local authorities can seldom afford to finance from local taxes or tariffs[4] (Kurian 2010).

This paper reports on findings of a study that combined a secondary review of 121 towns in India with a case study of a town in the 0.2–0.5 million-population category with the objective of filling knowledge gaps as they pertain to: (1) economic costs–benefits of wastewater reuse in the context of hypothesized links to climate variability; (2) the role of local farming practices, market conditions and crop variety in influencing wastewater reuse in agriculture; and (c) the role of inter-governmental financing in influencing selection of technical adaptation options for collection, treatment and disposal of wastewater. The subsequent sections of this paper discuss issues relating to seasonal and temporal rainfall variability, public health risks, links to quality of rural water supply and demand for agricultural water around urban centers. Technical and institutional options for adapting to climate variability through source separation of waste, treatment and reuse of domestic wastewater are also examined.

Climate variability and water services in peri-urban regions

Interdependence of water supply, wastewater and irrigated agriculture

In 2007, a major global demographic shift occurred—UNHABITAT notes that a majority of the world‘s population now lives in urban areas. There is clear evidence that secondary towns in the developing world are experiencing the fastest growth of urbanization. From the point of view of understanding the pressure this trend places on water resources, especially for regions characterized by inadequate infrastructure coverage, the analytic category of peri-urban is particularly interesting (Allen 2010). The peri-urban context refers to a situation where both rural and urban features coexist at the fringe of a city. From an environmental perspective, this interface is characterized by natural ecosystems, agro-ecosystems and urban ecosystem affected by material and energy flows (Allen et al. 2006:21). From a socio-economic viewpoint, the peri-urban interface exhibits peculiarities such as land speculation, changing land use practices and emergence of informal service providers. The peri-urban interface is also characterized by an institutional vacuum that makes it difficult to deal with challenges posed by rapid urbanization. This is evident from a convergence of sectoral and very often overlapping organizations with varying spatial coverage and jurisdictional mandates. Very often, roles and responsibilities for private, public and civil society players are not clear and municipal authority is weak.

With the demographic-political balance tipping ever more in favor of urban water consumers, it may also be expected that rural–urban competition for water will increase, and that rural (domestic and agricultural) consumers will be confronted regularly with extreme water stress, further supporting a move to the cities, and potentially creating food supply problems in these cities as far as direct hinterland provisioning is concerned (Dietz 2009). Some have predicted that strong political economy considerations are likely to lower future agriculture water allocations on account of rising demand for higher value urban water supply (IWMI 2007). With an increase in diversion of water towards water supply, one can expect an increase in urban wastewater generation—a rule of thumb being that approximately 80 % of urban water supply is

[2] Frank Rijsberman notes in his paper for the Copenhagen Consensus Project that approximately 20 million ha of land worldwide benefits from use of domestic wastewater for irrigated agriculture. His global review of sanitation options reveals that peri-urban wastewater reuse for agriculture has one of the highest high B–C ratios (Rijsberman 2004).

[3] Use of treated wastewater for peri-urban agriculture and using freshwater that is freed up as a result to meet the burgeoning need for high value urban water supply.

[4] In the case of water and sanitation, notable service delivery outcomes include connection to a sewer network and access to a sustainable source of water supply.

converted into wastewater. Untreated or unmanaged domestic wastewater today constitutes the largest proportion of total wastewater generated (industrial wastewater volumes are smaller) and poses the greatest threat to water supply sources: surface water and groundwater (Raschid and Rooijen 2010).

On-site and off-site sanitation options

In 2002, approximately 2,600 million people lacked adequate sanitation facilities. Most of these people live in urban areas. The Millennium Development Goal for Sanitation is to halve the number of people without sanitation by 2015. The most recent report of the Organization of Economic Cooperation and Development (OECD)[5] notes that the Joint Monitoring Program (JMP) definition of improved sanitation includes flush or pour flush toilet to piped sewer system, septic or pit latrine, ventilated improved latrine, pitlatrine with slab or composting toilet. However, facilities that are shared, public or used by large numbers of others, are not classified by the Joint Monitoring Programme (JMP) of the United Nations as improved, but in many situations this is a common situation. Further, in many cases, MDG targets focus on expanding coverage but do not address issues of sustainable financing—how will such facilities once created be maintained and operated? Unlike a rural context where incidence of open defecation may be lower, shared toilet facilities in urban areas service a large number of poor people with no access to septic tanks or connection to a sewer network. Depending on the size of the population being served by common facilities, public investment may be required to provide reliable water supply, organize regular cleaning and waste disposal.

Huge advances have been made in toilet design that make it possible to optimize on freshwater use for flushing and even to address specific local concerns relating to availability of space, ability to pay, privacy and security at night for women and children, and promotion of cultural acceptance of reuse options (Fig. 1).

From an urban sanitation standpoint, off-site sanitation also assumes an important role, especially given its close links to water supply. Off-site sanitation options could include the following:

Eco-san methods like composting toilets with/without urine diversion.

Settled sewerage that involves a sewer system receiving solids-free effluent from a septic tank, secondary wastewater treatment and effluent reuse in aquaculture, agriculture or horticulture.

Simplified sewerage systems receiving unsettled domestic wastewater. These systems have a sewer diameter in the range of 100 mm, self cleaning of sewers is ensured by using a minimum peak load of 1.5 L/s. Simple junction boxes are used rather than manholes.

Relative costs of sanitation options in high density and poor urban settlements

A growing number of studies have compared per-capita costs of onsite and off-site sanitation options in urban areas. As population densities in cities or peri-urban regions rise, adoption of simplified sewerage systems may lead to a 20–50 % cost-reduction when compared to conventional sewerage. Interestingly, in high density poor areas, simplified sewerage may even fare better than on-site sanitation systems[6] (Fig. 2). There are a number of advantages of exploring such options. For example, in the case of the Orangi project in Pakistan a poor community relies on public standpipes for water supply. Therefore, on plot water supply is not required to sustain a simplified sewerage system. In Brazilia (Brazil), the water supply and sewerage company installed simplified sewers in well-to-do neighborhoods using front yard or sidewalk sewers. Expenses for manhole covers that are incurred by conventional sewer technologies are overcome by simplified systems. The costs of operating and maintaining this system are recovered through a higher surcharge on the water bill.[7] More recently, others have argued that cost-recovery can also be supported by effective re-use of domestic wastewater in secondary towns that support peri-urban agriculture (Rijsberman 2004). However, empirical evidence suggests that customer involvement combined with political support from mayors and public sector agencies are critical for the success of such interventions (Allen 2010).

Addressing reuse risks of off-site sanitation

There are a number of risks associated with considering reuse options for off-site sanitation in urban areas. Three main reuse risks include: (1) pathogen transfer through

[5] OECD, February 2009.

[6] A World Bank financed loan of USD 20 million to promote use of condominial sewer technology in 2001 has resulted in increased water and sanitation coverage in Peru. Approximately 30,000 families benefited in the first phase. Unit cost of water and sewerage network has also been reduced by between 40–50 %.

[7] Some examples of tariff structures include the following: flat rates for water and tax on solid waste (Bangalore, India), sewerage charge = 50 % of water supply fee is allocated for sanitation operations and maintenance (Manila, Philippines), environmental charge of 10 % for water to cover cost of cleaning septic tanks (Manila, Philippines), sewage tax and sewer connection fee calculated based on built area, house insurance amount, pay use for communal systems and bank loans for new plants (Nyon, Switzerland).

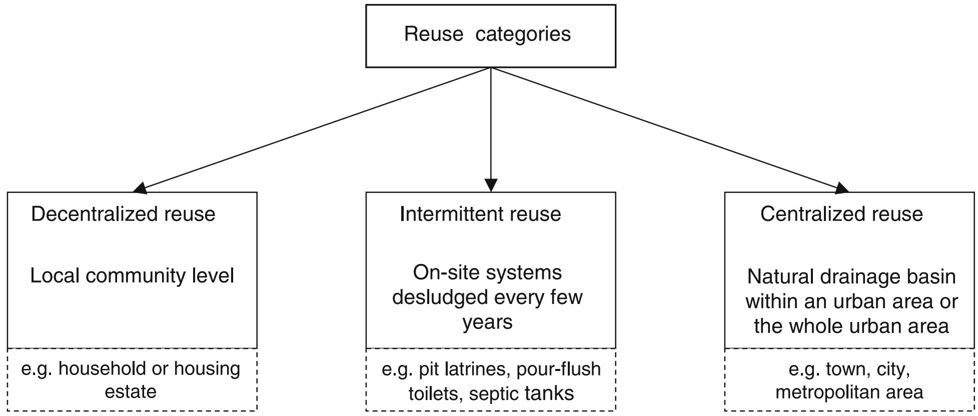

Fig. 1 Broad sanitation categories based on the arrangement of water and nutrient reuse. Source: Mara (2007)

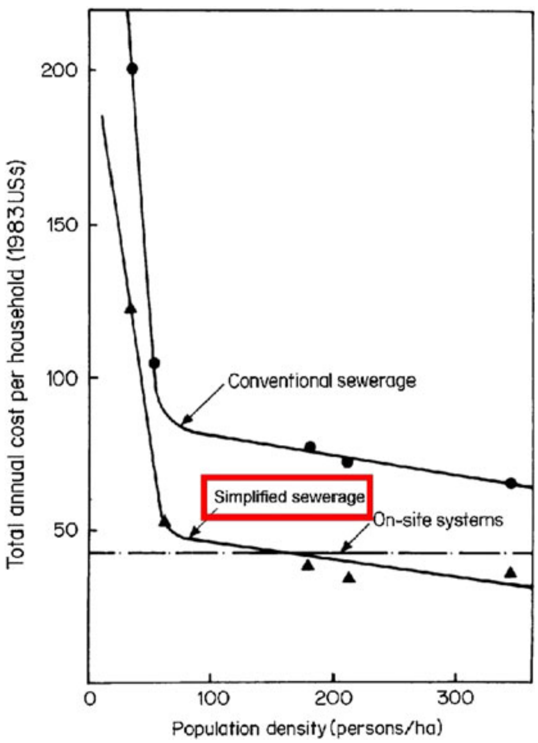

Fig. 2 Variation of costs of conventional sewerage, simplified sewerage and on-site sanitation with population density, Natal, northeast Brazil, 1983. Source: Mara et al. (2001)

contamination of groundwater based water supply sources (contamination of shallow tubewells due to poor cleaning and disposal of septic tanks); (2) pathogen transfer through contamination of food chain-crop quality; and (3) pathogen transfer disposal of untreated wastewater into rivers-water quality. The 2008 revised WHO guidelines make a serious attempt at identifying various reuse risks from water source to waste disposal by identifying indicators for environmental, soil and geohydrological parameters. An attempt is made to identify reuse possibilities together with associated risks for a range of agro-climatic contexts, including high rainfall or dry regions. The WHO guidelines also identify parameters for monitoring water quality depending on type of use—water for drinking or irrigation—and by levels of crop resistance to effluent pollution (WHO 2008).

Institutional responses to climate variability

Scientists and practitioners dealing with water are worried about the impact of climate change on water availability and quality. Greenhouse-gas induced temperature increases probably result in overall rainfall increases. This is good news for those who look at the growing imbalance between water demand and supply, particularly in water-stressed regions with increasing demographic and economic demands for higher water consumption. What is worrying, though, is the likelihood of changing weather patterns and higher climate variability, which will have a geographical and temporal aspect. Regional climate change scenarios predict major shifts in climate zones, although with much uncertainty about regional specificities: competing regional scenarios show major differences in potential outcomes. Where shifts are predicted from sub-humid to semi-arid conditions, particularly in areas with a dense population and intensive water demands, major problems can be expected (Dietz et al. 2004). However, the temporal aspect is probably even more worrying. All climates have an element of variability: between seasons, between night and day, between quiet and stormy conditions. Climate change scholars dealing with water impacts note with concern that seasons are shifting (e.g., the start of a reliable rainy season is becoming less dependable in many areas across the globe), and that variability is becoming more extreme. Periods of (extreme) droughts are feared to happen more often, but particularly periods of extreme rainfall, and storms are likely to increase, and become more extreme; with a higher concentration of rainfall in fewer days (or hours). All these aspects may have negative impacts on water management and calls for adaptation measures to cope with lower predictability and more extremes. Adaptation means a shift to more water sources, from a wider geographical environment (more interdependence). It also means better defense mechanisms against extreme events, both technically, and institutionally (Dietz 2009). In the following section, we explore some of the risks posed by climate variability based on a review of trends in the Indian context.

Trends in water supply, sanitation and wastewater reuse in Indian cities

Economic value of domestic wastewater

In India, the Central Pollution Control Board (CPCB) estimated that only 6,909 ha land is devoted to wastewater farming, while independent studies put this figure at above 100,000 ha (Scott et al. 2000). Apart from reducing water scarcity, especially in drought-prone regions, wastewater could be highly beneficial for agricultural purposes due to its high nutrient concentrations. It is estimated that wastewater contains 30 mg nitrogen, 7.5 mg phosphate and 25 mg potassium per liter (CPCB 2000). This amounts to 500 t nitrogen, 125 t phosphate and 416 t potassium per day and valued at Rs. 4.39 million per day from the class I cities. The total annual value of nutrients is estimated to be Rs. 1,595 million. With proper management this nutrient value can be transferred to crops and reduce the application of fertilizers. Revenues can be generated from farmers and used for treating the wastewater to mitigate its negative impacts.

Given the magnitude of wastewater generated, the extent of area irrigated could be more than 1.2 million ha in all the class I cities[8] and more than 0.35 million ha in the cities with population between 2 and 5 lakhs (Table 1). The total revenue generated with proper water pricing (water + nutrient value) are Rs. 1,828 millions (US$ 48.10 millions) and Rs. 539 millions (US$ 14.18 millions), respectively, for the two categories of towns. The revenue can more than cover the O&M cost of sewage treatment plants (STP), which is estimated in the range of Rs. 630–1,330 million (US$ 16.58–35 million) depending on the technology used for treatment,[9] while the capital costs are estimated to be in the range of Rs. 8,830–40,000 million (US$ 232.37–1,053.63 million) (CPCB 2000).

Extent of wastewater pollution of drinking water sources

During the monsoon months, wastewater can mix with storm water and inundate parts of town localities due to inadequate drainage facilities. While storm water reduces the negative impacts of wastewater during monsoon months, the excess flows during the season create other problems, such as flow of contaminated water to downstream locations. Most towns and villages located near rivers depend on the latter for their drinking water needs (Table 2). Only 8 % of towns in India depend purely on groundwater sources for drinking water supply, while 27 % depend purely on surface water sources. High dependence on surface water sources makes these communities particularly vulnerable to water pollution, as most untreated wastewater is discharged into river systems. The Godavari river basin has the highest dependence (81 %) on surface water, making its population the worst affected in the country. Even communities that depend purely on groundwater are not fully protected due to surface and subsurface water resource linkages.

Table 1 Wastewater generation, treatment and disposal in towns (0.2–0.5 million population) with/without a sewage treatment plant (STP)

Item	With STP	Without STP	Total
No. of towns	37	84	121
Population (millions)	11.60	24.4	36
Wastewater generated (MLD)	1,611.19	3,300.87	4,912.06
Wastewater treatment capacity (%)	29.90	–	09.81
Disposal into rivers	72	68	69
Disposal into agriculture fields	05	–	0.16
Disposal into surface water bodies	25	32	30.84

Source: CPCB (2000)

MLD million liters a day

Trends in rainfall variability

High variations in rainfall can cause problems for managing wastewater. While high rainfall years and regions need planning for handling large volumes for collection, treatment and disposal, low rainfall years and regions need planning for higher levels of treatment/dilution due to high concentration of pollutants. River basins with higher variations may have to plan for both. In the absence of effective management interventions, scope for productive use of wastewater for agriculture will be compromised. Our review of secondary data reveals that inter and intra river basin rainfall variability[10] is observable (Table 3). We

[8] Class I cities are categorized as urban centres with a population between 2.5 and 5 million.

[9] These technologies include, up-flow anaerobic sludge blanket (UASB), activated sludge plant (ASP), trickling filters (TF) and oxidation pond (OP). Of these, ASP is the most expensive followed by TF, UASB and OP. But, land requirement for OP is more than three times that of the other techniques.

[10] It may be noted that rainfall data are not available consistently across stations, especially in recent years. For some, data are available until 2004, for some until the late 1990s and for some until the early 1990s. In some cases, data is available intermittently. Coefficients of variation (CV) are calculated only for the last 30 years for which data are available.

Table 2 Coverage and sources of water across river basins

River basin	Total water supply (MLD)	Source of supply (%)			Population covered by organized supply (%)
		Ground	Surface	Combined	
Brahmani	21.56	0	100	0	75
Brahmaputra	145.47	7	21	72	46
Cauvery	920.40	1	25	74	85
Ganga	8,886.85	8	15	77	89
Godavaro	771.36	0	81	19	93
Indius	757.85	37	28	35	79
Krishna	1,719.70	1	50	49	90
Mahanadi	394.35	29	56	15	87
Mahi	206.20	0	00	100	80
Narmada	160.66	0	08	92	93
Pennar	80.10	0	64	36	96
Sabarmati	660.17	3	4	93	99
Subaranarekha	358.54	0	100	0	93
Tapi	356.20	0	51	49	81
Sub-Total	15,439.41	8	27	55	88
Coastal	4,071.28	1.5	84	14.5	88
NMB/NC	1,096.55	27	48	25	86
Grand total	20,607.24	7	39	54	88

Source: CPCB (2000)

Table 3 Rainfall variability across river basins during the last 30 years

River basin	No. of sample towns	Mean rainfall (mm)	Variations during the last 30 years			Range across towns in the basin		
			Minimum	Maximum	CV	Minimum	Maximum	CV
Brahmani	NA[a]	NA	NA	NA	NA	NA	NA	NA
Brahamaputra	NA	NA	NA	NA	NA	NA	NA	Ni
Cauvery	2	760	625	849	12	501	1,029	10–14
Ganga	4	1,067	494	1,671	14	389	2,004	10–20
Godavari	4	863	591	1,067	13	442	1,269	8–19
Indus	NA	NA	NA	NA	NA	NA	NA	NA
Krishna	6	758	483	976	19	396	1,300	9–52
Mahanadi	1	968	436	1,392	24	436	1,392	24
Mihi	1	567	240	749	28	240	749	28
Narmada	NA	NA	NA	NA	NA	NA	NA	NA
Pennar	1	556	438	631	13	438	631	13
Sabarmati	NA	NA	NA	NA	NA	NA	NA	NA
Subarnarekha	NA	NA	NA	NA	NA	NA	NA	NA
Tapi	2	757	756	758	10	550	919	10–11

The range for the towns in the river basin (for which data are available). In some river basins data is available for only one town. Source: Estimated from the rainfall data provided by Central Research Institute for Dry land Agriculture (CRIDA)

CV Coefficient of variation

[a] Not available

have taken 5-year moving averages to avoid extreme variations. The range in rainfall (min–max) appears to be higher in the high rainfall river basins like Ganga, Mahanadi and Godavari. The year-on-year fluctuations indicate that rainfall patterns are either stable or increasing in most cases. While the Ganga basin falls in the high rainfall zone (>1,000 mm), Krishna, Godavari and Cauvery fall in the medium rainfall (>750 mm) zone, and Penna and Mahi fall in the low rainfall (<700 mm) zone. Of the four important basins, the rainfall pattern in Godavari basin shows a positive trend in the majority of the stations, while the low rainfall basins indicate a declining rainfall pattern. High annual variations (CV) are observed in the case of Krishna and Godavari basins. A review of rainfall and temperature trends in Karimnagar town (situated in Godavari river basin) between 1985 and 2002 indicates that both rainfall and temperature variability has increased. Rainfall variability for the period 1985 and 1989 was 14.3, as compared to 29.4 for the period between 1990 and 1994. During the period 1998 and 2002, rainfall variability increased further to 34.5. For the same periods the maximum temperature variability was 1.6, 1.4 and 3.4, respectively.

Data and methods

To examine the effects of climate variability on water supply and wastewater in secondary towns, Karimnagar town and villages utilizing wastewater discharged from the town for peri-urban agriculture were selected for a detailed study. In Karimnagar town, four wards prone to wastewater stagnation were selected. Here, the focus was on seasonal flow analysis, discharge and aggregation points, health impacts (incidence of mosquitoes, malaria, water borne diseases, etc.). Among the surrounding villages, one (Bommakal) is affected directly as it uses wastewater directly for agriculture and livestock purposes, and another (Alaganur) is a victim of the secondary impact of wastewater. Alaganur uses the wastewater discharged into the Manair River for agricultural purposes. Until recently, Alaganur used an infiltration well on the riverbed for drinking water purposes, but shifted to a new source after water contamination became a problem. Alaganur is a typical case representing number of villages located in river basins across the country. These two villages are ideal sample points for assessing the impacts. Another two villages—Srinivasanagar and Lakshmipura—that use the Manair riverbed as a drinking water source (infiltration wells) were selected for assessing the downstream impacts of wastewater on drinking water and health. One village (Chegurthi) was selected as a control sample to assess the impacts. The socioeconomic and demographic profile of the sample villages is presented in Table 4. Water quality samples were collected from six points within Karimnagar town and from seven sites downstream of the town. The sample sites were representative as they were selected depending on the end use of sewerage discharge and storm water collection at various locations in the study area.

Water quality, public health risks in cities and rural livelihoods

Domestic wastewater and water quality: a case study

Karimnagar District is situated within the geographical coordinates of 17-5 Northern latitude and 78-29 Eastern longitudes; and is 480 m above sea level. The normal rainfall of the District is 966.2 mm with moderate temperature except at Ramagundam, which records the highest temperature of 48 °C during April–May in the State. Agriculture is the main activity, with a gross cropped area of 0.423 million ha, of which 56 % is irrigated. The main crops raised in Karimnagar District include rice, maize, green gram, chilies, turmeric, cotton, and groundnut. The Sri Ram Sagar Project is a Major Irrigation Project. There are 5,353 tanks and 1,98,567 wells and 7 other minor projects providing irrigation. Major industries include coal mines of Singareni Collieries at Godavarikhani, N.T.P.C. at Ramagundam, Kesoram Cement Factory at Basanth nagar

Table 4 Basic features of selected villages in vicinity of Karimnagar town

Village	Total cultivated area	Population	#Households	Number of families[a]			Road connectivity	Distance from nearest town
				S&M F	MF	LF		
Bommakal	1,800	5,000	1,000	550	150	30	Very well connected	5 km (Karimnagar)
Alugunur	1,600	Above 10,000	1,550	500	110	25	Very well connected	6 km (Karimnagar)
Srinivasanagar	350	1,264	291	135	5	0	About 10 km from highway	10 km (Karimnagar) 21/2 km (Manakondur)
Laxmipur	1,550	1,638	385	170	90	15	Good	12–15 km (Karimnagar) 6–7 km (Manakondur)
Chegurthy	580	2,116	385	190	30	6	Poor	18–20 km (Karimnagar)

Source: Author's field survey

S&M F small and marginal farmers (0.1–2 acres land ownership), *MF* medium farmers (2.1–5 acres land ownership), *LF* large farmers (greater than 5 acres land ownership)

[a] Remaining are landless and families involved in employment

and Nizam Sugar Factory at Muthyampet. Karimnagar municipality is one of the biggest in Telangana region of Andhra Pradesh, with an area of 26.85 km^2. The town is divided into 50 wards with 32 notified slums and 16 non-notified slums while another 10 are recommended for recognition, accounting for a total of 58 slums. There are ten Gram panchayats[11] on the periphery of Karimnagar, which are proposed to be merged with an estimated current population of 275,000. The town is well connected by road with other cities.

At present, water is released to households on alternate days on a turn-taking basis. Water is released from reservoirs above from 6 a.m. to 6 p.m. every day, covering half the area under each reservoir on a single day and the remaining area on the next day. The process is then repeated. In addition to this there are 26 tankers mounted on tractors of 3,000–4,000 l capacity, which continuously supply slum as well as elevated areas. On average they make around 80 trips in a day. In addition, 0.77 million liters a day (MLD) water is also supplied from bore wells. Over and above this there are 770 hand pumps, of which 755 are in working condition for supplementing water for domestic use. Besides, 40 % of households complement the organized water supply with open or bore wells. Water is supplied through 24,380 individual tap connections and 1,000 public stand posts to ensure 135 litres per capita daily (LPCD). The total domestic wastewater generated amounts to 22,210 cum/day (22.21 MLD).[12] During the 5 months of the rainy season, the total wastewater generated in the town ranges between 133,950 cum/day (133.95 MLD) and 170,844 cum/day (170.84 MLD). Storm water drainage is more than six times that of wastewater generation during the peak months. Table 5 indicates that wastewater released within the town (locations S1–S6) did not meet environmental and water safety standards. While none of the sample sites are suitable for drinking water, water is suitable only for irrigation in the case of filter beds (S12).

Public health risks in slums

Residents of slums are worst affected as a result of poor wastewater management in Karimnagar town. Discussions revealed that every rainy season residents are forced to vacate their houses at least once or twice, leaving all their belongings as water floods into their houses. They have to stay in temples or in buildings that are under construction, or sometimes even on elevated roads. The duration of this ordeal depends on the intensity of the rain. Sometimes this may go on for days, during which time people depend on the municipal authorities for water and food. The monsoon period of 2007 was the 3rd consecutive year when houses were flooded and old houses damaged. Apart from inadequate drains, the main reason for this, according to women in the slums, is the encroachment of common areas like ponds and other open places where water used to be stored. It was observed that open wells are located within a distance of 2 m from wastewater drains, with greater chances for contamination. Households use the well water for domestic purposes such as washing clothes, cleaning utensils, bathing, etc., as the municipal/public tap water is sufficient only for drinking due to its alternate-day supply. During the rainy season, the wastewater overflows into the open wells, at which point people discontinue using the wells for 10 days and resume after disinfectant treatment by the Municipality. During these days they depend on water from hand pumps, which generally smells of rust and is brown in color. When asked about the contamination of wells, the women reported that the water smells bad and tastes salty but they can do very little about this as they cannot afford the individual connections, and even if they own one it is difficult to construct the overhead tank for their small houses. Between 300 and 500 washer men make productive use of untreated domestic wastewater. The average income per family is about Rs. 5,000–6,000 (USD 100 per month) and some who wash clothes for hospitals and educational institutions earn a little more. Water quality has deteriorated dramatically in the last 12–15 years because wastewater is discharged directly into the river. Washermen develop itching and irritation of skin leading to wounds and ultimately to fever. The problem is severe in summer and is less in the rainy season due to the flow of fresher water.

Costs and benefits of untreated wastewater in downstream villages

About 454 acres of land is being cultivated with the wastewater draining from Karimnagar town. As our water quality analysis shows, fecal coliform (FC) contamination in Bommakal village is 2.5 times higher than WHO guidelines (1,000 FC/100 ml). Mixing of storm water with wastewater will help in meeting WHO standards through a reduction in levels of MPN coliforms. Studies have indicated that these guidelines are appropriate in hot climates, especially for restricted cropping (cereals, pulses etc.). MPN coliform contamination levels of above 1,000/ml are found to affect the quality of vegetable crops like radish and lettuce (Bastos and Mara 1995; Blumenthal et al. 2001). Farmers who were interviewed at our study site

[11] Gram panchayats are units of formal local government in India. In Andhra Pradesh they are the lowest unit of local government that corresponds to the unit of a village or a group of villages.

[12] The magnitude of wastewater will increase once ten surrounding villages are merged with Karimnagar town. These villages have a population of 37,709 and expected to generate about 4 MLD wastewater.

Table 5 Quality of wastewater across sample locations

Parameters	Normal range	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
pH	7.0–8.5	7.6	7.5	7.3	7.9	7.2	7.6	7.4	7.6	7.9	7.6	7.8	8.1	7.6
EC (mho)	750	1,469	1,232	1,468	1,478	1,225	1,539	1,369	1,225	1,125	772	813	379	1,444
TDS (mg/l)	500	954	800	954	960	796	1,000	889	796	731	501	5,284	246	938
Chloride (mg/l)	200	130	170	164	168	140	236	216	164	140	80	92	28	228
Fluoride (mg/l)	1	0.24	0.16	0.19	0.18	0.16	0.24	0.20	0.27	1.76	0.20	0.22	0.10	0.29
Nitrate as NO_2 (mg/l)	45	56	92	116	107	84	78	72	84	72	24	65	06	96
Nitrate as NO_3 (mg/l)		N	N	N	N	N	P	P	N	N	N	T	N	N
Total harness (mg/l)	100	430	430	396	356	328	408	420	364	312	220	196	160	376
Alkalinity (mg/l)	75	560	384	484	480	368	460	392	352	368	268	256	140	388
MPN coliforms/ 100 ml (after 48 h)	<50 for drinking <1,000 for irrigation	2,400	2,400	2,400	2,400	2,400	2,400	552	918	348	240	918	348	240

Source: Original field data collected by authors with assistance of municipal engineers. Water samples were tested at the State Level Referral Institute, Hyderabad

P Present, *N* not present, *T* trace, *TDS* total dissolved solids, *EC* electrical conductivity, *S1* Swashakthi college (town), *S2* Collector office (town), *S3* Civil Hospital (town), *S4* Rythu Bazar (town), *S5* Bommakal bi-pass, *S6* Dhobi Ghat, *S7* Bommakal village, *S8* Sadasivapalli, *S9* Srinivasnagar, *S10* Vegurupally, *S11* outdoor, *S12* filter bed, *S13* Chegurthy

opined that paddy can be grown with wastewater on their lands as there is continuous availability of water.

Cultivating with wastewater may be more economical in terms of expenditure but the health risks involved for humans and livestock and the returns from crops make it disadvantageous, especially in comparison to crops grown under open well or river/tank/canal irrigation (Table 6). To gain a better understanding of the risks, investments and returns are calculated. Wastewater irrigation is characterized by low investment, low yields and lower market price. Due to the higher nutrient value of wastewater, farmers do not apply pre-sowing fertilizer, which is valued at Rs. 1,000[13] (US$ 26.3). On the whole, farmers save about Rs. 400 (US$ 10.5) per acre on the cost of cultivation. On the other hand, the yield difference is about 7 quintals per acre. This, coupled with the Rs. 50 difference in the price of paddy, means that farmers using wastewater end up with a gross return of Rs. 13,650 (US$ 359) per acre as compared to Rs. 19,600 (US$ 516) per acre of well-irrigated paddy. However, due to the assured availability of wastewater, farmers grow two crops.

Better management of wastewater can improve returns by approximately six times on account of double cropping and lower expenses on pesticides from the 454 acres presently under cultivation with wastewater. Presently, two crops of paddy are grown in comparison with rain-fed maize crop, which was grown prior to the availability of waste water (Table 7). Paddy yields under better managed wastewater are assumed to be equivalent to the yields under groundwater irrigation. Besides, better managed waste water would have higher nutritional value and reduce fertilizer costs. Thus, the net additional benefits from 454 acres after netting out the returns from maize comes to US$ 28,674 at present and US$ 185,184 with better managed wastewater (groundwater).

It is important to recognize that, depending on the location of individual plots, farmer's stand to benefit differently from interventions aimed at improving management of wastewater. Farmers with plots at the upper end of the distributor canal incur higher costs due to a higher incidence of pest attack. This is due to the fact that, at the starting points of the distributor, canal water stagnates and is not drained out due to continuous flow from the town every day. Crop yields also tend to be lower at 25–28 bags and grain quality is poor. On the other hand, farmers in the middle of the distributor canal get about 30–35 bags and suffer moderate risk of pest and flood damage, while farmers who cultivate at the tail end receive around 35–38 bags and experience less risk of pest attack.

Treatment of domestic wastewater would greatly reduce the risk of contaminating the Manair river, which is a primary source of drinking water for downstream villages. Our case study village of Bommakal has a 60,000-l capacity overhead tank connected to an infiltration well in the Manair river. A previous infiltration well had to be abandoned due to wastewater contamination. A new infiltration well was dug a little above the riverbed, and water is pumped to the tank with a 10 HP motor and the tank gets

[13] 1 USD = INR 38.

filled every day. There are 400 household connections and 7 public taps in the village. Of the seven taps, two are non functional. Only 5–7 % of the households still use this water for drinking as the majority of families stopped using these taps over the last 10 years. Villagers go to Karimnagar to fetch drinking water, and almost 30 min–1 h is needed to fetch two cans of water (about 40–50 l); in summer this becomes worse as people are required to wait 2–3 h.

Around 20 families buy the 20-l cans supplied by mineral water vendors at a cost of Rs. 15 (US$ 0.39) per can on alternative days. Approximately Rs. 3,600 (US$ 95) is spent on water annually. Using cost of avoidance/prevention, replacement cost and travel cost methods, we estimate that the total cost of water contamination comes to Rs. 3.37 million (US$ 88,763) per year for the entire village (Table 8). In addition to costs incurred by humans, the study also found that households also incurred veterinary costs on account of livestock falling sick. On average, expenses for livestock due to contamination of water sources amounted to Rs. 425 annually per household in Bommakal village.

Table 6 Investment and returns to paddy crop under wastewater and well irrigation (Rs./acre)

Wastewater irrigation		Well irrigation	
Type of operation	Investment (Rs.)	Type of operation	Investment (Rs.)
Ploughing	2,000	Ploughing	2,000
Seed	500	Seed	500
Urea	1,000	Urea	1,000
Labour (planting)	800	Labour (planting)	700
Pesticides	600	Pesticides	200
Labor (weeding)	500	Labor (weeding)	400
Transport	1,000	Transport	1,000
Harvesting	1,000	Harvesting	1,000
Total Investment	7,200	Total Investment	7,600
Yield/acre	30–35 bags	Yield/acre	35–40 bags
No. of quintals	21 quintals	No. of quintals	28 quintals
Rate/quintals	650–700	Rate/quintals	700–750
Return/acre	13,650 (USD 359)	Return/acre	19,600 (USD 516)

Source: Reddy and Kurian (2010)

Climate variability and water services: adaptation pathways

Rationale for wastewater separation at source

Untreated domestic wastewater use is known to cause public health risks but none of these costs are presently being internalized in water supply projects. Given the interconnectedness of water supply and sanitation, there is a strong case for advocating integrated costing models for urban water supply projects and combined billing of sanitation services. The sanitation challenge is water borne (in its scale and reach), and solutions are most likely to be found by emphasizing the public health risks it poses. The important point to emphasize in this context is that reducing public health risks of unmanaged domestic wastewater is politically not as challenging as arguing for full cost recovery for water supply projects. For example, in 2006, Indonesia lost an estimated IDR 56 trillion (USD 6.3 billion) due to poor sanitation and hygiene, equivalent to approximately 2.3 % of gross domestic product (GDP). Poor sanitation also contributed significantly to water pollution—adding to the cost of safe water for households, and reducing the production of fish in rivers and lakes. The associated economic costs of polluted water attributed to poor sanitation exceeded IDR 13 trillion (USD 1.5 billion) per year. Poor sanitation also contributed up to IDR 11 trillion (USD 1.2 billion) per year in population welfare

Table 7 Benefits and costs of wastewater irrigation in Bommakal

Particulars	Wastewater irrigation			Total income from wastewater	Additional benefits (net)	With treated/better managed wastewater
	Before	After (Kharif)	After (Rabi)			
Crop area (acres)	454	454	454	908	454	908
Area irrigated (acres)	00	454	454	908	454	908
Crop grown	Maize	Paddy	Paddy	Paddy	Paddy	Paddy
Gross value of produce (Rs./acre)	12,000	13,650	13,650	27,300	15,300	39,200
Cost of cultivation (Rs./acre)	1,500	7,200	7,200	14,400	12,900	13,200
Net returns (Rs./acre)	10,500	6,450	6,450	12,900	2,400	26,000
Total benefits/year (for 454 acres after netting out for rain fed maize)	–	–	–	–	1,089,600 (US$ 28,674)	7,037,000 (US$ 185,184)

Source: Author's field survey

Table 8 Costs of water pollution in Bommakal village (humans)

Indicator	No. of households	Economic cost per households/year in Rs.	Total cost in Rs./year
No. of households buying water	20	3,600	72,000
No. of households fetching water from town	900	3,650 @ each households spends an hour per day in fetching water; the wage rate is Rs. 10 per hour	3,285,000
No. households drinking contaminated water	80	200 (medical expenses)	16,000
Total	1,000	7,450 (US$ 196)	3,373,000 (US$ 88,763)

Source: Reddy and Kurian (2010)

losses (due to additional time required to access improved sanitation), IDR 1.5 trillion (USD 166 million) per year in tourism losses, and IDR 0.9 trillion (USD 96 million) in environmental losses due to loss of productive land. A number of intangible effects, relating to the population's preferences for a safe, convenient and private place to defecate, were not quantified in this study but are known to influence population behavior and galvanize politicians to take decisive action (WSP 2008).

The sustainability of traditional/conventional sewer networks has recently been questioned. Analysis show that sewer networks are still the most efficient transport system and that, despite the fact that sewers are 50 % more expensive than combined sewers, there is an increasing trend of connection to separate sewers, atleast in developed parts of the world (RIONED 2005). Associated costs per capita served are still low in comparison to individual wastewater treatment systems in remote locations where sewer connections are not feasible (Wilsenach 2006). Regardless of alternatives presently available, one can expect that sewer networks will remain a sanitation backbone, especially in densely populated urban areas. However, contrary to the opinions of those who are constantly working on improving conventional wastewater systems, there is an emerging movement supporting alternative sanitation and urban water drainage that promotes pollution prevention rather than control, separation at source rather than at end-of-pipe treatment, and re-use of valuable resources rather than wasting by discharge into the environment. In this context, it is believed that source separation of rainwater and urine has the best prospects for improving urban water management (Wilsenach 2006).

Urine separation could improve the efficiency of treatment processes, which would support the philosophy of 'closing the loop' and recovery for nitrogen and phosphorus. Another futuristic option is to promote separation of faeces (dry sanitation), which is currently implemented at experimental sites (mostly new urban developments in Western Europe) where full separation at source has been implemented (separate collection and separate handling/treatment of yellow, grey and black water). This approach deviates from the conventional sanitation practice for urban areas (sewerage system and end-of-pipe treatment) and promotes the principle of on-site treatment (which can still be centralized) and resource recovery. The wider applicability of such an approach and its feasibility in densely populated areas remains to be seen, especially in developing countries. In institutional terms, the challenges that arise in developing countries could relate to: (1) norms that would facilitate integration of water resources management from source to reuse-addressing issues of sectoral water allocation; (2) norms for costing[14] of water supply and sanitation interventions that would reflect costs of separating waste at source; and (3) norms for billing of water supply and sanitation services, especially in contexts where multiple service providers from public or private sectors are involved (Salome 2010).

Accountability and autonomy of inter-governmental relations

Public choice theory has emphasized that if sufficient autonomy is granted to local authorities, it may be possible to mobilize local finances and skills to address regional environmental challenges like wastewater pollution of rivers (Oates 1972). However, on the contrary, when central fiscal transfers do not allow for greater autonomy it may be difficult to hold local authorities accountable for their revenue and expenditure practices. For example, based on a cost–benefit (C–B) analysis that we undertook, the Karimnagar local government was presented with a set of wastewater management/treatment options.[15] These options ranged from the creation of oxidation ponds

[14] Project costing can be influenced by aspects of current design of water infrastructure where sizing of primary settling tanks, aerobic tanks and anoxic tanks as well as of aeration equipment and eventual addition of external carbon source for denitrification. It is to be expected that urine separation will help avoid extension of existing plants or construction of new plants; however, the bottleneck will likely be the hydraulic capacity of the plant. The latter can be improved by introduction of water saving devices within water supplies, wider introduction of water meters, awareness rising among water users, and separation of rainwater and sanitary sewers.

[15] In the absence of scientific evidence, we assume that better managed waste water irrigation is equivalent to well irrigation + higher nutrient value. Such an assumption has limitations but is not unusual in C–B analyses.

Table 9 Costs and benefits of wastewater treatment plant at 2.5 % discount rate over 15 years (in million rupees)

Costs–benefits	UASB	ASP	TF	OP	MOP+
Capital costs (25 MLD)	74.13	80	77.5	17.5	1.00
O&M costs	1.30	2.63	1.88	1.30	0.05
Total value of benefits	10.84	10.84	10.84	10.84	10.84
Net present value (NPV)	46.42	23.60	38.42	101.66	132.64
B–C ratio	1.53	1.21	1.40	4.12	84.16

Source: Authors field survey

UASB up-flow anaerobic sewage blanket, *ASP* activated sludge plant, *TF* trickling filter, *OP* oxidation pond, *MOP* multiple oxidation pond

(highest C–B ratio) to construction of an up flow anaerobic sewage blanket (UASB) plant, which had the lowest benefit cost ratio (Table 9). Despite the availability of more cost-effective options for wastewater management as demonstrated by our study, the local government preferred the UASB option since central funds were available for its construction. This fact reflects an important aspect of fiscal behavior that relates to the structure of inter-governmental relations. Inter-governmental relations are characterized by multiple sources of central funding, some conditional and some unconditional. In many cases, donor projects constitute an important source of these central resource transfers (World Bank 2006). As long as central transfers are not tied to accomplishment of policy outcomes like connection of poorer households to a sustainable source of water supply or connection to a sewer network, central transfers will only encourage dependence of sub-sovereign entities without emphasizing a search for cost-effective and efficient means of service delivery.

In recent years results-based financing strategies have been supported by external agencies and include: output based aid (OBA) and budget support. A number of lessons have been learnt from such interventions in the case of water supply and sanitation (Kurian 2010):

- The importance of predictable policy frameworks that delineate roles of private, public sector and civil service organizations in planning and implementing water projects.
- The importance of donor harmonization in ensuring that donor financing is coherent and consistent with strengthening links between disbursements and achievement of policy outcomes.
- The importance of local planning, which would acknowledge the diversity of institutional contracts, competing political interests and the incremental nature of policy change.
- The importance of fiscal incentive schemes in achieving behavior change—moving from an exclusive focus on infrastructure creation to monitoring the delivery of affordable and reliable services.
- The importance of inter-governmental budgeting norms that enhance accountability of revenue and expenditure of sub-sovereign entities.
- The importance of real-time information mechanisms for monitoring and acting upon service delivery targets at multiple governance levels (donors, national, and local authorities).

Conclusions

This paper reported the findings of a study of water and sanitation services in India. The secondary review indicates that untreated domestic wastewater that enters rivers is a major source of contamination of drinking water sources. Data from major river basins in India, pointing to both increasing rainfall and temperature variability, further exacerbates the need for cost-effective wastewater management options. Our case study of Karimnagar (located in Godavari river basin) demonstrates strong links between wastewater generated during high rainfall months and storm drain overflows. Climate variability has an effect on public health of slum populations in Karimagar town, peri-urban agriculture practised in outlying villages and river quality. Poor river quality due to untreated wastewater from Karimnagar town had a direct effect on public health. Public health links were evident from skin rashes experienced by washer men and spread of disease among both human and livestock populations in downstream villages.

An important finding of this paper relates to the economics of wastewater reuse. Cultivating with wastewater may be less financially viable as compared to cultivating with well water. Further, when we consider health risks for humans and livestock and returns on crops, a number of interesting perspectives emerge. Firstly, because of better nutrient value of wastewater, farmers do not apply fertilizer. Further, due to assured availability of wastewater, farmers can grow two crops. On the other hand, farmers spend more on pesticides due to high incidence of pests (whitefly and jassid) under well irrigation. Wastewater reuse for agriculture is sensitive to soil and crop type; in our study area only paddy could be grown using domestic wastewater. Crops grown using wastewater sell for less in local markets compared to crops grown using well water. Our study also found that better wastewater management had the potential to increase returns of wastewater agriculture by up to six times because of double cropping and lower expenses incurred on fertilizers. Depending on the location of individual plots, farmers also potentially stood to benefit from higher crop yields because of lower risk of flood damage and pest attack. Therefore, we may conclude that, although a huge potential exists for wastewater reuse in agriculture, its effectiveness as an adaptation pathway may depend on critical aspects of local farming practices, market conditions, crop varieties and implementation of cost-effective treatment measures that facilitate wastewater reuse.

Adaptive management could also take the form of technical measures that support source separation of wastewater: separating urine from rainwater or total separation of solid and liquid waste. In many instances, as pointed our earlier, the viability of source separation measures may depend on integrated costing of water supply projects to reflect the costs of separating waste at source. Further, combined billing of water supply and sanitation services may also be necessary. The actual realization of these measures will depend on the structure of inter-governmental relations: hierarchy of local government structures, norms for fiscal transfers between different levels of governments and legal and policy framework that outline roles of public, private and civil service players in the provision of water services (Salome 2010). In this context, a promising adaptation pathway is to enhance the accountability and autonomy of local authorities (governments/utilities) to ensure identification of cost-effective technical interventions for delivery of water and sanitation services. If the accountability and autonomy of local authorities is to be enhanced, a critical examination of norms that currently guide inter-governmental relations in general and donor financing in particular would be a prerequisite (World Bank 2009).

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